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IMAGE PROCESSING OF DIGITAL CARTOGRAPHIC DATA.(U)
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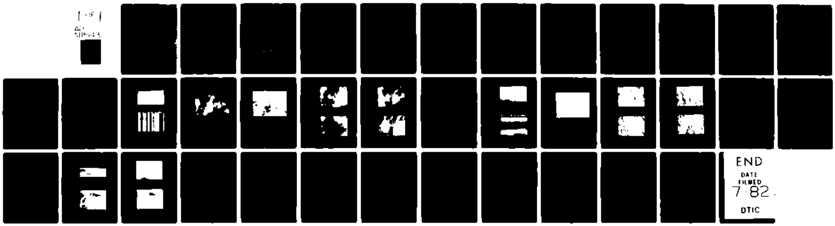

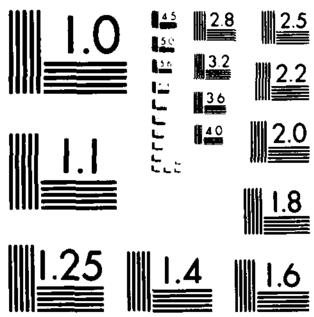
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A CONCISE DESCRIPTION OF THE TECHNIQUES OF COLLECTING, STORING, PROCESSING AND DISPLAYING OF CARTOGRAPHIC DIGITAL DATA ON AN INTERACTIVE RASTER DISPLAY DEVICE THE IMAGE MANIPULATION STATION.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Cartographer has long been interested in depicting surface features of the earth as a pictorial representation. This representation has normally consisted of pen and ink drawings in an easily referenced format. The ability to assure both quality and accuracy became two of the primary concerns of the Cartographer in the production of maps and charts.

This paper details the rapid advancement of Cartography through the introduction of micro and minicomputers in the management and quality accuracy determinations of digital elevation and cultural information. Advantages

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and disadvantages of the new processing techniques are clearly stated. The algorithms and programming techniques are discussed with emphasis placed on resultant enhancements utilized by the cartographic analyst.

The major theme for this paper is the methods used at DMA to review the digital data bases through the use of the Image Manipulation Station. System configuration, components, software development and image utilization are discussed. These comments are directed toward the various images (gray-coded, shaded relief) and the quality assurance verification techniques associated with the image enhancements.

1

IMAGE PROCESSING OF DIGITAL CARTOGRAPHIC DATA

GERALD W. JOHNSTON

PRESENTED TO THE XII ASSEMBLY
PAN AMERICAN INSTITUTE OF GEOGRAPHY AND HISTORY

Santiago, Chile 1982

DEFENSE MAPPING AGENCY
AEROSPACE CENTER
ST LOUIS AIR FORCE STATION, MISSOURI 63118

RESUMEN DE UNA PONENCIA QUE SERA PRESENTADA ANTE:

LA XII ASAMBLEA GENERAL DEL IPGH

INSTITUTO PANAMERICANO DE GEOGRAFIA E HISTORIA

SANTIAGO, CHILE   22-27 MARZO 1982

POR: GERALD W. JOHNSTON
PHYSICAL SCIENTIST
DMA AEROSPACE CENTER
ST. LOUIS, MISSOURI

TITULO: PROCESAMIENTO DE IMAGENES DE DATOS CARTOGRAFICOS DIGITALES

Desde hace tiempo el cartógrafo ha querido representar las características de la superficie terrestre en forma pictórica. Esto se ha hecho normalmente por medio de dibujos a pluma y con un formato de fácil referencia. La capacidad de garantizar tanto calidad como exactitud en la producción de mapas y cartas ha pasado a ser una de las mayores preocupaciones del cartógrafo.

En esta ponencia se detallan los grandes adelantos alcanzados en el campo de la cartografía con la aplicación de las micro y minicomputadoras al manejo y determinación de la calidad y exactitud de la información digital sobre elevación y accidentes artificiales. Se exponen claramente las ventajas y desventajas de las nuevas ténicas de procesamiento. Además se explican los algoritmos y técnicas de programación pertinentes, poniendo de relieve el consiguiente mejoramiento utilizado por el analista cartográfico.

El tema principal de esta ponencia consiste en los métodos empleados por la DMA para revisar las bases de datos digitales por medio de una Estación de Manjo de Imágenes. También trata de la configuración de los sistemas, sus componentes, la preparación de los programas y la utilización de las imágenes. Los comentarios se extienden a los diversos tipos de imágenes (código de Gray, relieve sombreado) y a las técnicas de control de calidad relativas al realce de las imágenes.

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FROM: GERALD W. JOHNSTON

PHYSICAL SCIENTIST GS-12

TITLE: IMAGE PROCESSING OF DIGITAL CARTOGRAPHIC DATA

The Cartographer has long been interested in depicting surface features of the earth as a pictorial representation. This representation has normally consisted of pen and ink drawings in an easily referenced format. The ability to assure both quality and accuracy became two of the primary concerns of the Cartographer in the production of maps and charts.

This paper details the rapid advancement of Cartography through the introduction of micro and minicomputers in the management and quality/ accuracy determinations of digital elevation and cultural information. Advantages and disadvantages of the new processing techniques are clearly stated. The algorithms and programming techniques are discussed with emphasis placed on resultant enhancements utilized by the cartographic analyst.

The major theme for this paper is the methods used at DMA to review the digital data bases through the use of the Image Manipulation Station. System configuration, components, software development and image utilization are discussed. These comments are directed toward the various images (gray-coded, shaded relief) and the quality assurance verification techniques associated with the image enhancements.

INTRODUCTION

The cartographer/geographer has long been interested in discovering new methods that would enable him to examine and portray natural or man-made features on the earth's surface. The established procedure has always involved the pen or pencil to simulate, at various scales, the features of all or a portion of the area of interest. This simulation could be geographic, geologic, demographic, cultural, or economic information. The amount and type of information to be portrayed is as varied as the imagination.

For years this type of cartography was limited by the time required to gather, compile and display information at required scales. With the aid of computers, the cartographer has been able to make quantum leaps in data manipulaation to display meaningful information in chart form.

I intend to discuss in this paper the gathering, handling and graphic display techniques of various types of digital data. Since my work has primarily been in the area of terrain display and manipulation of related topographic data, such topics as culture, population and economic geography will not be covered to the same extent. These areas of concern will be left to the scientist or technical expert with the interest, imagination and expertise to develop the algorithms necessary to incorporate these subjects into the graphic display system.

Graphics processing is important in scientific, academic and industrial environments. In the past, graphics systems had been used with large computers and were available to only a few users. The relatively small and specialized use of graphics has inhibited sharing software and has prevented standardization necessary for widespread use. The advent of the minicomputer or microprocessor has enabled a wide variety of users to become involved in graphics processing.

The graphic display of digital data is a relatively new field. It began in the early 1960's with work accomplished at MIT, General Motors, Bell Telephone Laboratories and Lockheed Aircraft and flourished during the so-called Age of Computers. By the 1970's, these research development centers were producing meaningful displays

The modern graphics display is relatively simple in construction. It consists of three components: A digital memory (minicomputer) or "frame buffer" in which the image is stored; a graphic display monitor (similar to a TV set); and a simple interface, called a display controller, that passes the contents of the memory or frame buffer to the monitor.

Inside the frame buffer of raster display systems, the image is stored as a pattern of binary numbers representing a rectangular

array of picture elements or pixels. In the simplest case, where a black and white image is to be stored, black pixels can be represented by 1's and white pixels by 0's. The display controller reads each successive byte of data from memory and converts the 0's and 1's into the corresponding video signal. The signal is then sent to the graphics monitor and the image is displayed. Typically, many more shades of gray are used to depict terrain data thus increasing the complexity of required image display algorithms.

The Defense Mapping Agency (DMA) produces and maintains cartographic digital data bases in support of DoD operations. These data bases include terrain elevations over various geographical areas, stored in matrix formats of varying intervals. In DMA Standard Format, the elevation data bases are arranged into one degree by one degree geographic areas. The spacing of horizontal points in an elevation array is three arc seconds in both directions if the data are located at less than 50 degrees of latitude. Thus, a data base comprises a matrix of 1201 x 1201 points (3600 seconds of arc by 3600 seconds of arc or a one degree quadrangle).

To examine the data bases quickly and carefully the Image Manipulation Station, or IMS, has been developed. It consists of a color raster display system interfaced to a minicomputer with a magnetic tape drive and disk storage device. These units will be discussed later.

The adage that a picture is worth a thousand words is widely accepted by the educational and scientific computing community, although only a fortunate few have had access to devices which provide adequate graphic interaction. The power of graphics to communicate is due primarily to their ability to create figures with a clear and deep semantic meaning. Displays of structures, cross sections, drainage, and other topographic features are displayed with few symbols but convey complex concepts.

DEVELOPMENT OF DIGITAL IMAGE PROCESSING SYSTEM

The primary considerations when developing a digital image processing system are as follows:

1. Digital Data Collection and Storage
2. Digital Data Image Processing and Graphic Display
3. Graphics Image Hardware

Each of these functions will be addressed in the discussions which follow. These discussions will center on the development of such a system for cartographic applications.

DIGITAL DATA COLLECTION AND STORAGE

When capturing and storing digital data, consideration must be given to multi-user requirements. Depending on these requirements, the system may accept different input types, captured from different sources such as field surveys, maps/charts, photography, remote sensing and statistical data. Additionally, file structures or data base design will be directly influenced by the multi-purpose nature of the system. The system should also allow the user to produce different types of output such as gray-shaded or multicolor displays, and/or topographic or thematic displays.

Digitizing

A data base consists of data which has been captured by some method. The most common method for the capturing of data is the manual digitizer. This method employs a digitizing table, manually controlled cross-hair cursor and the necessary disk storage facility, memory processor, and operating system.

For cartographic applications, each element of data in the data base will be determined by its location and description. The location can be given by either geographic or raster matrix coordinates. The description can be recorded as either a numerical value or textual information. This positioning and describing function can be accomplished either during or after the digitizing phase.

The data elements consist of points, lines and areas. Using the coordinates as spatial definition in the digitizing of cultural features:

1. Points are defined by their coordinates.

2. Lines are defined by the connections between a series of successive points, sometimes as near as .05mm to each other.

3. Areas are defined by a series of successive lines forming the perimeter.

In the gathering of terrain elevation data, the surface is defined by a number of three-dimensional data points distributed in a regular or irregular pattern.

There are several manual digitizing systems utilized at the Defense Mapping Agency. One is the Lineal Input System (LIS), utilized for terrain and cultural information. This system consists of a table 36" by 56" with an automatic coordinate storage device controlled by a hand-moved cursor. The source material is registered to the table with the desired scale and minimum/maximum south-to-north and west-to-east geographic coordinates of the graphic to be digitized. This method enables the data to be placed inside a known geographic boundary. The corners are then registered in matrix coordinates, which coincide with the geographics. In the case of terrain data, elevations of contour lines are input and the contours are "traced", inputting the elevation of the contour each time a new contour is digitized.

All points along any given contour are now transformed to matrix coordinates with a known elevation. This data is then stored on the disk unit for easy retrieval. Editing is accomplished interactively to insure accuracy to within the standards of the source material.

A non-manual method of gathering digital data is the photogrammetric method. This method is the most expensive, most complex, most time consuming and the most accurate. It uses aerial photography which requires extensive control points for scaling and collecting the digital elevation data.

After acquiring the photography, much of the actual gathering of the digital data is automatic. The instrument scans the photos in a south to north direction and collects the data, in a digital format, as profiles. Since many photographic pairs are required to cover a desired area, a one degree quadrangle of data may take several weeks or months to complete. However, once the data has been collected, it is very accurate and easy to utilize in a graphic display system such as the IMS.

Date Base Utilization

Although it is difficult to anticipate every type of application for digital cartographic data, a multipurpose data base should meet as many user requirements as possible. There are two major user requirements for digitally stored elements.

1. What the elements represent, i.e., codes, elevations or descriptions of some type.
2. Where the elements are located, i.e., measured geographic coordinates.

Since terrain elements do not fill every need for the digital data, cultural features must also be digitized and stored in a similar data base. However, cultural information must also include such things as drainage, shore lines and other distinguishing features which will enhance the culture and terrain data. Most of the features are gathered from photographic source material, transferred to large manuscripts by hand and then digitized.

When considering cultural data, the information is distinguished by point, line or areal features as mentioned previously. Areal features can be described by a set of successive line elements forming the area's perimeter, separating two different types of areas (tree coverage from soil, etc.). A description of these line segments must be stored with the digital data for later display on some graphics medium.

Line features such as rail lines, shore lines or power lines also have a description stored in conjunction with them. Point features are representations of a feature of insufficient size to display or represent as an area. Much of the point feature representation depends on the scale at which the information is to be displayed.

The processing and presentation of these digital elements depend on the availability of the source material and the hardware and software to display the digitized information. The IMS utilitizes the digital data through software routines developed at the Defense Mapping Agency Aerospace Center in St. Louis, Missouri.

Computer-assisted cartography is considered as the process of capturing, storing and using digital point, line, areal and terrain elements. The application of digital display techniques becomes much simpler when the descriptions of these uses are given in the form of text rather than numbers or mathematical formulas.

DIGITAL DATA IMAGE PROCESSING AND GRAPHIC DISPLAY

Once the digital data has been collected and placed in some easily accessible data base, computer graphics can be utilized to give an easily understood and recognizable pictorial representation. Computer graphics can be partitioned into three phases. Data input and construction of data bases, transformation of those data bases into graphic format and the output of pictures and images are the primary functions of the graphic display systems.

For input into the elevation data bases for the models used in the IMS, a matrix of digitized points is most commonly used. This graphic image processing system will, however, use other forms of digital data discussed in the first section of this paper.

Terrain Display

The most commonly used and the most effectively displayed on the graphics system at DMAAC is the terrain model. This data can be gathered in any of several methods as long as the final result is a matrix. The matrix used in our graphics display system consists of 1201 rows, each containing 1201 points. This matrix size can vary depending upon the hardware to be utilized and geographic area to be displayed. A one-degree cell of data may be displayed in various matrix sizes by varying the number of displayable points according to the desired interval or geographic latitude.

On the IMS,the first step in building the graphic display image is reading the data from one storage medium to another. Data is initially stored on a 9 track magnetic tape at 1600 bpi density. The data is read from magnetic tape, passed through a minicomputer and stored on a disk unit for easy retrieval. Simultaneously, the data is passed through the graphics control unit, a minimum and maximum value is determined, and a shade of gray is assigned ranging from white for the lowest band of elevations to black for the highest band of elevations. The graphics hardware in the IMS allows up to 256 levels of gray coded information to be displayed at any one time.

Gray-Coded Image

Sixteen levels of gray are assigned to the elevation values to produce a gray-coded image. The human eye can not differentiate among 256 levels of gray on the raster screen. The shades of gray are assigned according to where the elevation values fall within the total range of the elevation matrix.

The gray-coded image for the IMS graphic display system is built as follows. The first elevation value in the row of data contains an X coordinate and a Y coordinate. This set of coordinates is stored to determine the beginning screen coordinate of that row of information. Each elevation value is then read from the tape. The first elevation point is read and stored in a location called minimum and a location called maximum. When the second elevation point is read, it is checked against the first to determine if it is larger or smaller. If the second point is larger, the second point is stored in maximum and the first point is kept in minimum. If the second value is smaller, that value is stored in minimum and the first is kept in maximum. This point-to-point check is performed over the entire 1,442,401 points in the 1201 x 1201 matrix.

After the entire data base has been recorded and the maximum and minimum values determined, another algorithm assigns a specific shade of gray to every point. The minimum elevation is subtracted from the maximum to define a range for the entire data set. Depending upon how many intervals or how much detail is desired, the range of elevation values is then divided by a predetermined number. This could be any number from 1 to 256. For the purpose of viewing the terrain data, sixteen levels are considered appropriate. This gives the analyst the overall feel for the topography of the area of coverage.

For further clarification, the cartographer may need to view zero elevations as a separate color or shade and may need to view the maximum and minimum values as a separate color or shade. To provide this enhancement, all points are mapped through a color table. Zero elevations are colored light blue, minimum elevations are dark blue and maximum elevations are bright green. All other elevations are mapped through the 16 shades of gray according to the band in which they reside.

In summary, to produce a gray-coded image with colors for minimum, maximum and zero elevations, the following set of algorithms can be used.

(1) Read point number 1 and store the value in minimum and maximum.

(2) Read the second value and check if larger or smaller than first value.

(3) Read and check all points in the same manner as step (2).

(4) Subtract minimum from maximum to determine range of elevations and divide the range by the number of bands of gray desired.

(5) Set up a color table with shades of gray in the proper locations.

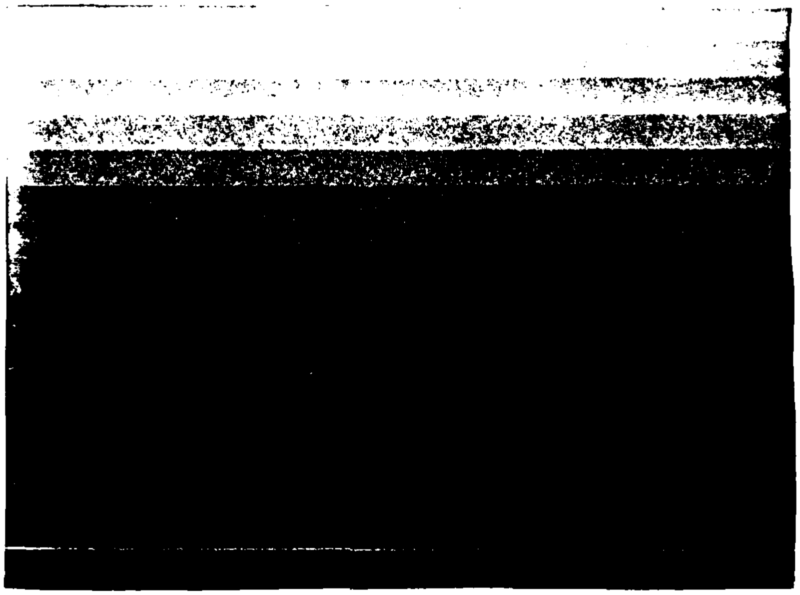
To add color to any band of elevations, change any gray band or color table position to the desired colors. Color table number 1 displays a gray-coded color table from white to black in 16 equal bands. The actual elevation data in gray codes from this color table can be seen in data Photos 1 thru 6. Color table number 2 is a random vertical distribution of gray codes.

To further enhance a common gray-coded image, any or all of the gray codes can be changed to color. The amount of color can be varied up to 256 levels at any one time. These colors can be selected from a total of 4096 possible shades of colors. Since the monitor is a RGB (red, green and blue) type, combinations can be derived to provide any color combination the analyst desires. These colors can be changed to any color combination to enhance any details the analyst may want to view. They can be "rolled" through software provided with the system so that the colors can be relocated within the color table. Programmer interactive systems, such as the stand-alone IMS, allow rapid changes to be made as the user requirements are determined.

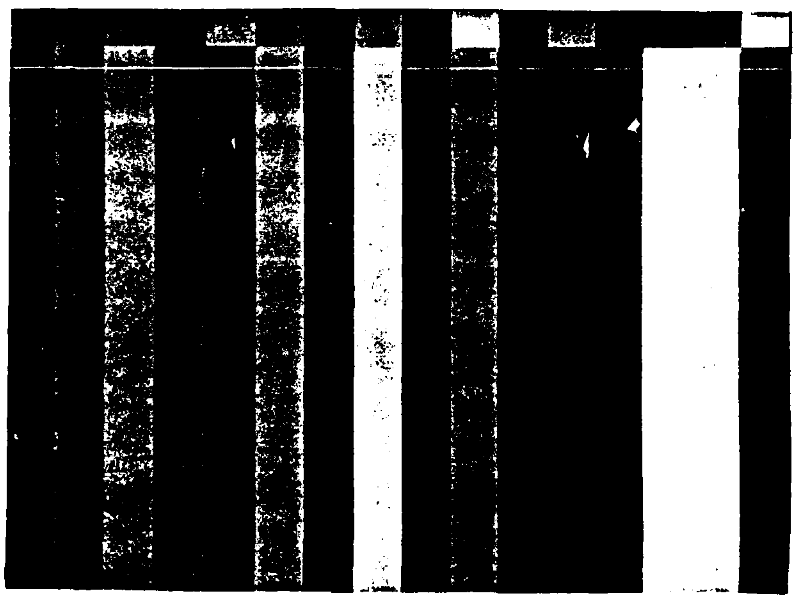
Shaded-Relief Images

Since the geographer/cartographer can not always identify every detail of surface topography by viewing gray-coded images, other ways of viewing the same area have been developed. Three dimensional mapping and air brushe renditions have been widely used for many years but consumed countless man-hours of detailed intense work. Through the use of computer graphics, a time-saving and valuable method has been developed to produce the same effects - shaded-relief. A shaded-relief view is extremely valuable to the analyst. This algorithm was developed from an averaging of matrix values and a determining of the percent of slope in a specific direction. Since the terrain model has been produced by reading the elevation data to a storage facility, that array of elevation values can easily be retrieved. Each point has a single value representing its elevation at a given X and Y coordinate. This relationship gives rise to an easy way of representing a shaded-relief image in various degrees or shades of gray.

The shaded-relief image is developed by averaging the three values to the north and west of a fourth value and double-weighting the one value to the northwest. The first row of



Color Table 1. White-to-black gray-coded video look-up table.



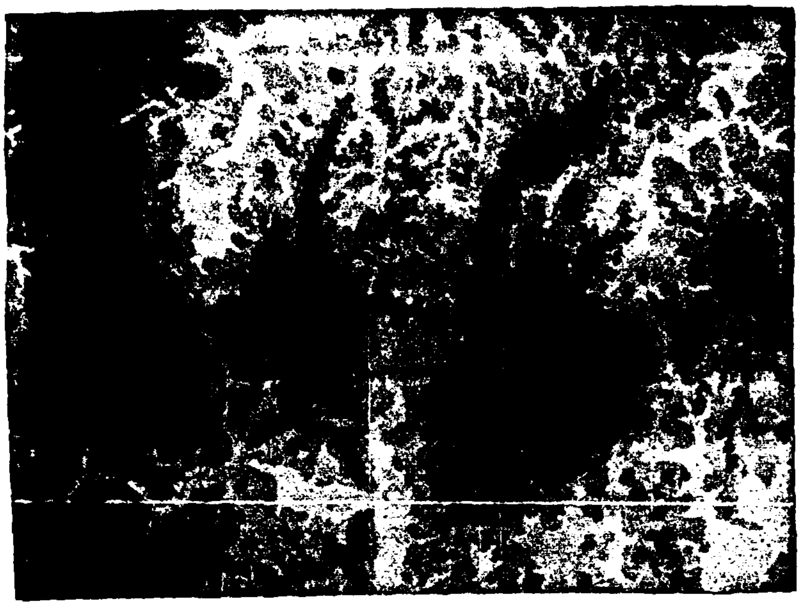
Color Table 2. Vertical random gray-coded video loop-up table.

Data Photograph 1. A full 1^{o} cell of terrain data displayed at reduced resolution in 16 shades of gray. White represents the lowest band of elevations and black the highest band of elevations. North is to the right in all illustrations.

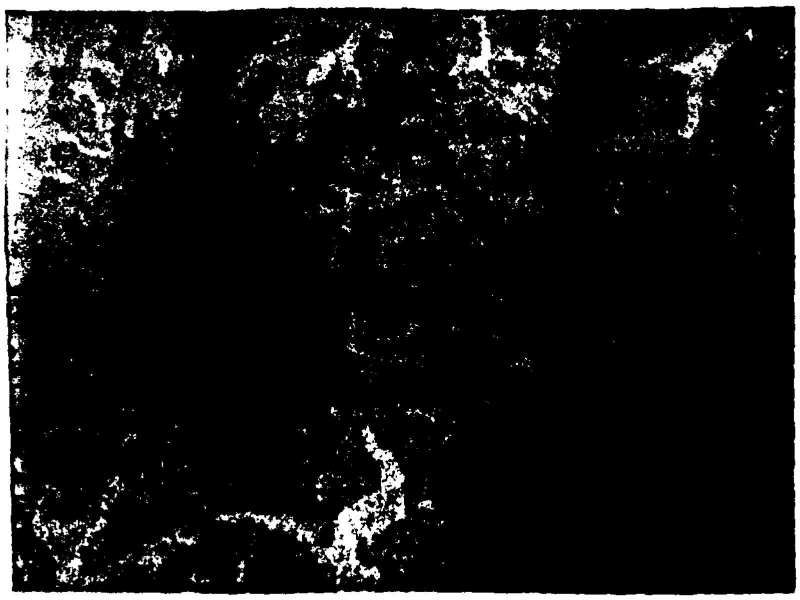
Data Photograph 2. The same 1^{o} cell of terrain data as in Photo 1 with the gray video look-up table reversed.

Data Photograph 3. The gray coded display of the lower left corner of the 1^{o} cell of terrain data displayed *in Photo 1. This image* displays a 512 x 512 matrix from the entire 1201 x 1201 matrix.

Data Photograph 4. A 2X enlargement of a portion of Photo 4. This image displays a 256 x 256 matrix from the 512 x 512 full resolution image.



Data Photograph 5. A 512 x 512 full resolution matrix of terrain data.

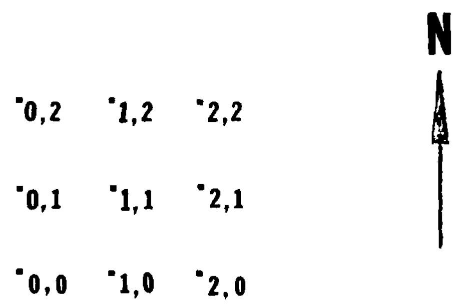


Data Photograph 6. A 2X enlargement of a portion of the terrain data in Photo 5.

elevation points is input and assigned a value according to the next point in the row. The second row of values is read into memory from storage. Points 1 and 2 of the first row and point 2 of the second row are added and averaged and a difference is determined in relationship to the first point of the second row of values. A table of values is then established over the entire area. By reversing the gray-coded look-up table as in color table number 3, low values are now dark and higher values are lighter shades. This system produces a series of tones with lighter shades facing in the northwest direction. Examples of black and white shaded-relief are shown in data photographs 7 thru 11.

SHADED RELIEF ALGORITHM

3 POINT SHADED RELIEF (ELEV. DIFF.)

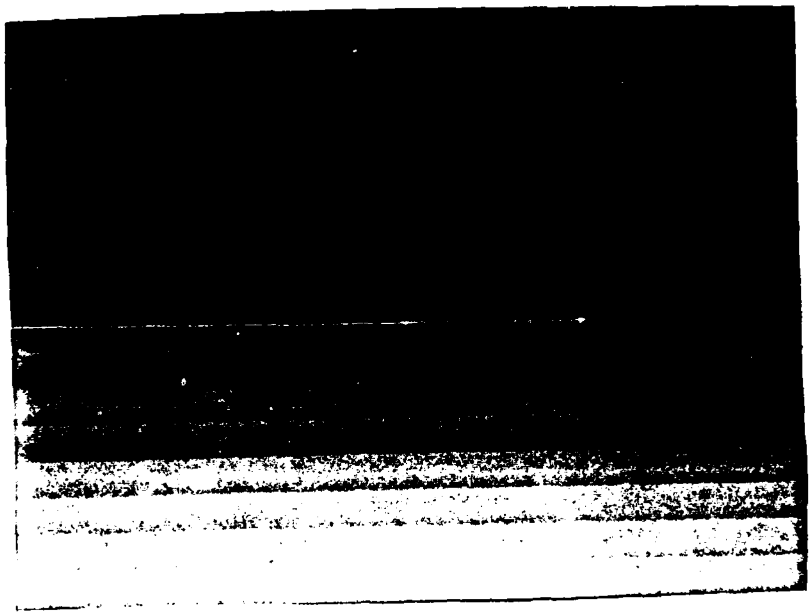


E = ELEVATION VALUE

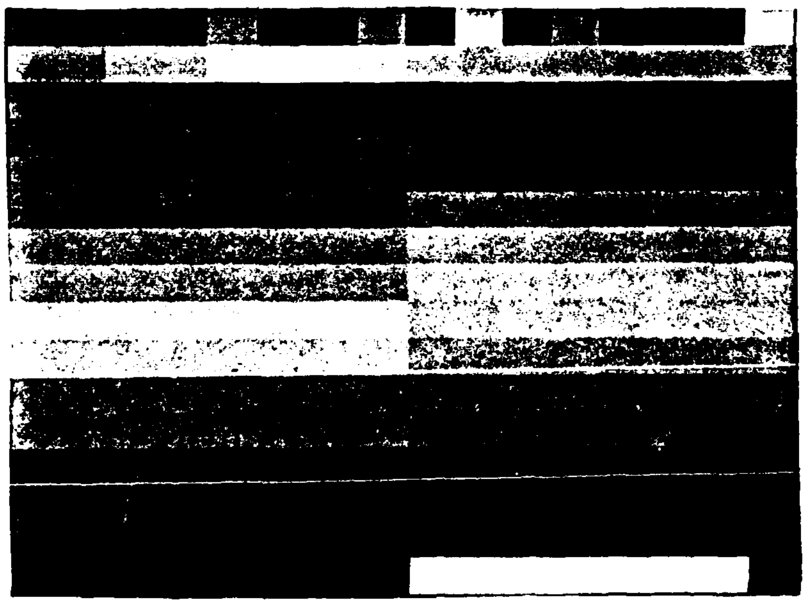
$$\Delta E_{1,1} = \frac{\frac{(E_{0,1} + E_{1,2})}{2} + E_{0,2}}{2} - E_{1,1}$$

or,

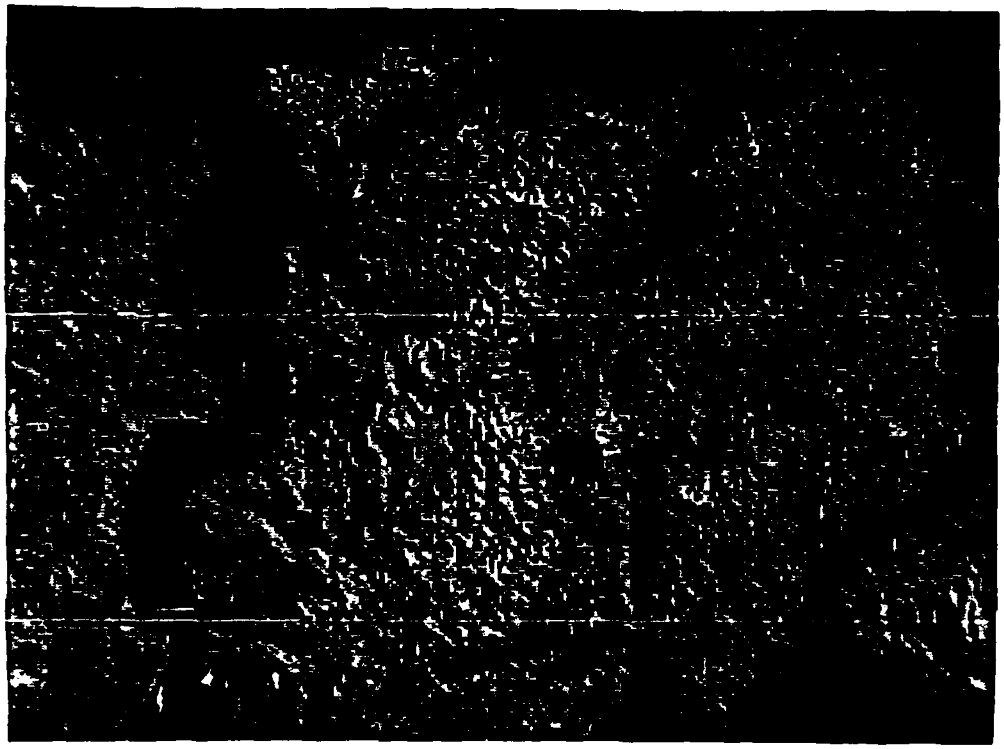
$$\Delta E_{1,1} = \frac{E_{0,1}}{4} + \frac{E_{1,2}}{4} + \frac{E_{0,2}}{2} - E_{1,1}$$



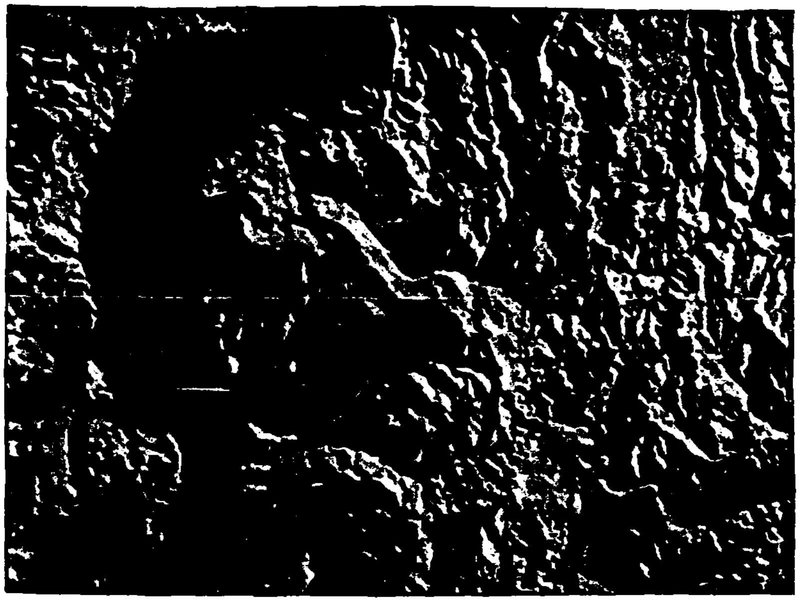
Color Table 3. Black-to-white video look-up table for international gray-coded display (black for low elevations). This look-up table is also used for the shaded-relief display.



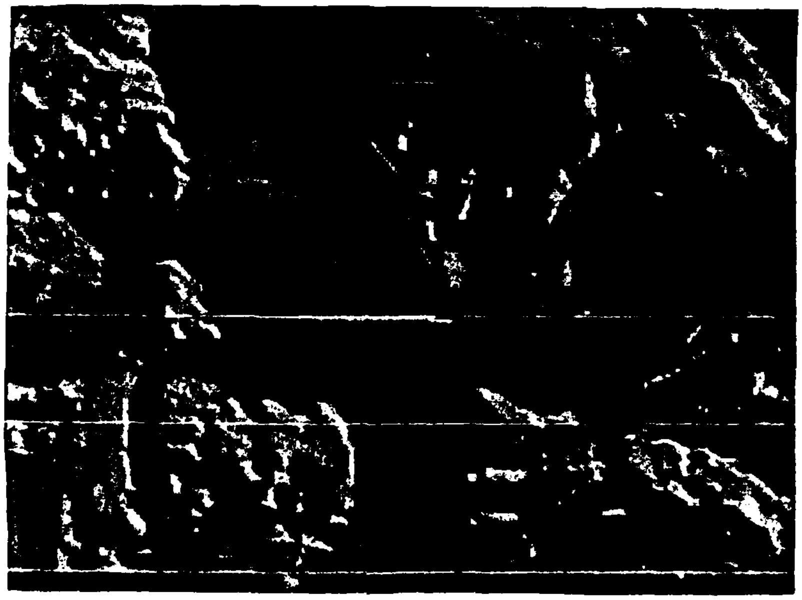
Color Table 4. Random gray scale video look-up table.



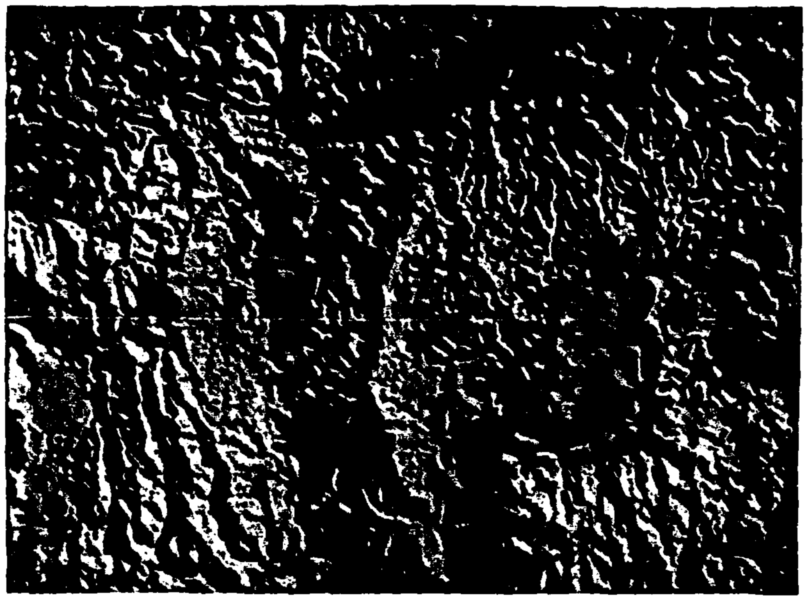
Data Photograph 7. A black and white shaded-relief display of the same 1° cell as shown previously. The "blockiness" is due to a reduced resolution using only a small portion of the available data. The artificial sun is in the upper right corner which is northwest in the photograph.



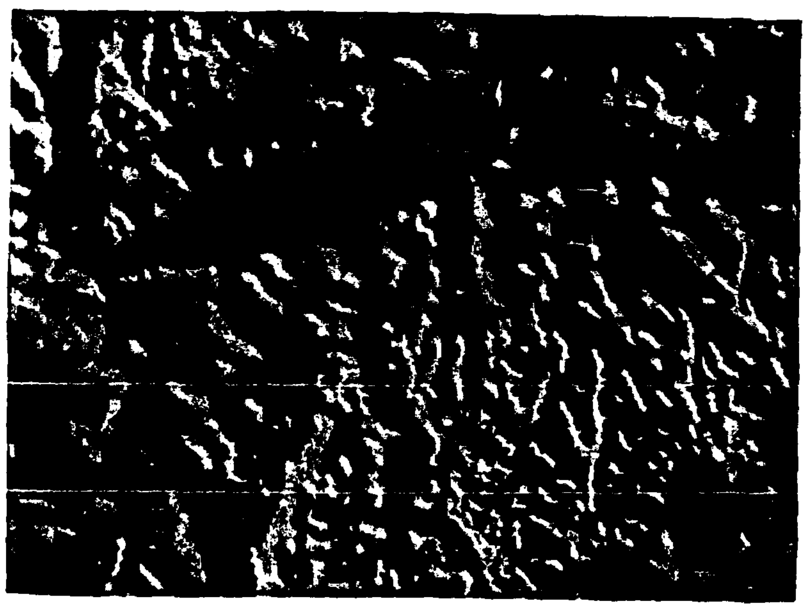
Data Photograph 8. The shaded-relief view of the same portion of the 1^{o} cell of terrain data as shown in Photo 4. Anomalies such as straight line features in the river valley are more definitive in the shaded-relief image.



Data Photograph 9. A 2X enlargement of the river valley showing the straight line features. This is an actual 50 meter break in adjoining terrain elevation values depicting an error in the data.



Data Photograph 10. A full resolution shaded relief display of the same area as in Photo 6.



Data Photograph 11. A 2X enlargement of the upper central portion of Photo 10 displaying a depression and two straight line features. These anomalies are not of sufficient magnitude to be classified as errors.

With the shaded-relief image to enhance the analysts' view of a given terrain area, many more features will stand out. With the standard gray-coded image many anomalies are blended in with the surrounding area. However, with a shaded-relief image, errors or unusual elevation data will appear much more prominent giving the cartographer a better opportunity to select areas of concern.

To further enhance the cartographer's view of the data, color can be added in place of any shade of gray. This format simulates ground color or map colors so the analyst will get a feel for the actual topography of an area. The only problem which exists with this color scheme is the blue colors. Blue in the tinted shaded-relief image will represent the lowest band of elevations, not necessarily water or zero elevations. The difference can be shown by displaying the blue areas in the shaded relief view and the light blue areas in the gray coded image which are actual zero elevations. The shaded relief image does display anomalies such as the incorrect data in the river (the straight line) in data photos numbers 8 and 9, which are an enlarged view of the lower left corner of the full 1^{o} cell of data in photo 7. The simulated sun in the shaded relief images is in the upper right of the photographs. North is, therefore, to the right in all of the displays. The reason for aligning the data in this direction on the graphic display monitor will be explained in the next section.

The analyst will establish an operating procedure through experience and use of the graphic processing image display system. Since much of the data is gathered from source material in chart form, the producer of the digital data may decide to use the map color display to assure the information is correct. Since shaded-relief improves and enhances some aspects of the analysis of the data, some analysts may choose this display scheme. Since much of the data is collected from stereo pairs. Some analysts may be more comfortable with viewing the terrain data in an anaglyph stereo configuration.

Anaglyph Stereo Image

A red and blue anaglyph stereo image is possible only after a shaded-relief image has been built and stored. This, as far as I know, is the only system now in production using a red and blue image to simulate anaglyph stereo.

As discussed previously, the gray coded image was built storing the selected gray code in the right 8 bits of a word containing 16 bits of information. The tinted shaded relief was then developed with the result of the averaging algorithm stored in the next higher four bits. Since all of this information was readily available, an algorithm was dev loped to produce, in theory, two more images; one blue and one red.

The actual averaged difference between points in a northwest direction was known as a result of the shaded relief algorithm. To add the stereo capability, a different ratio has been developed. As the difference in elevation from point to point changes, the rate of shifting the red image changes.

The distance of the image to be shifted is determined by the difference between the maximum elevation and the minimum elevation divided by 16, since the maximum amount of shift is 16 bits or pixels (one bit per pixel). If the difference between 2 points falls within one of the 16 ranges, that red value is shifted that number of pixels to the right to simulate parallax. If there is no change, the red image is not shifted and the resulting image displayed appears as a flat neutral gray. If the elevation is the maximum within the cell, the blue image remains constant and the red image is displaced 16 pixels (the maximum amount) to the right and is shaded lighter toward the northwest. If the change is a negative, the image is not shifted and is shaded darker blue to simulate a negative shift.

For orientation purposes, north is located to the right of the image area. The production techniques used to achieve the stereo image requires this rotation. Since the differences in elevation are checked along each scan line rather than between or across different scan lines, the scan lines have to run in the same plane as the human eyes. The scan lines run north and south, thus the graphic image has to be turned so that the scan lines run horizontal.

To view the data in stereo, a pair of glasses with a red lens and blue lens must be used. Since the red image is shifted to the right, the blue lens must cover the right eye. If the glasses are worn in the opposite manner, a pseudo-anaglyph stereo rendition can be seen. The IMS stereo viewing capability is most useful to the analyst who is accustomed to using stereo compilation in compiling

the terrain data. The analyst determines the view, color combinations or information he wishes to use to enhance the terrain elevation data.

Cultural and Economic Image Processing

The geographer/cartographer is equally desirous of viewing man's impact on the surface of the earth. Cultural data is also digitized and processed in much the same manner as terrain data. Cultural data elements include descriptions of each qualifying feature. One of these descriptions involves construction material or natural material. These surface material categories (SMC'S) can be coded so that a separate color is assigned to each. If the analyst wishes to display concrete, th t SMC may be coded and assigned the color orange. This area may then be plotted to coincide with digital terrain data and overlayed. Water may be coded blue, power lines red and metal structures white. Soil may be color coded brown with rocks being white. Any feature may be designated by any of the 4096 colors. To enhance the viewing perspective, the color should contrast with the background colors of the terrain.

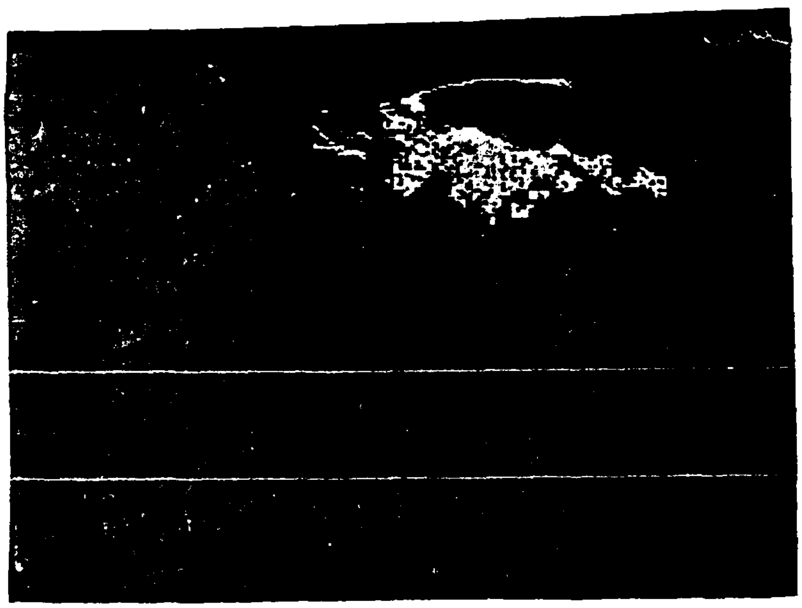
Data photographs 12 through 15 display a city and its port facilities in gray shades. This cultural data has been overlayed with a shaded-relief terrai view of the geographic area.

These highlighted areas can be changed to fit the economic geographers desires. Land use, percentage of the coverage or density, percent of occupied areas, water areas or drainage patterns can be determined by changing the required parameters.

The ability to change these parameters is extremely important to the digital display processing system. The Census Bureau has been using this type of system for several years. The primary concern of an image processing system of this sort is rapid production of color coded statistic map displays. The hard copy products previously used (and still produced) take weeks or months to produce. By utilizing the graphics image processing system, the time for production is reduced to a few seconds or minutes by interactive graphics display.

The major step in developing a statistical capability of this magnitude is to digitize a base map display which can be used for repeated enhancement. For example, a choropleth map display can be produced showing unemployment rates across the U.S. The statistical information is readily available from sources accessible to everyone. To produce a meaningful standarad line drawing would require weeks of work. If the

Data Photpgraph 12. A perspective view of terrain data overlaid by culture data. This is a reversed view of the photograph below at 30 degrees from the horizon.



Data Photograph 13. A perspective display of terrain data overlaid by culture data as viewed from the zenith.

Data Photograph 14. A low resolution display of gray coded culture data.

Data Photograph 15. A 2X enlargement of the port facility and surrounding culture information as shown in Photo 14. A comparison between Photo 13 and this photo shows a clear definition of the terrain enhancement to the culture data.

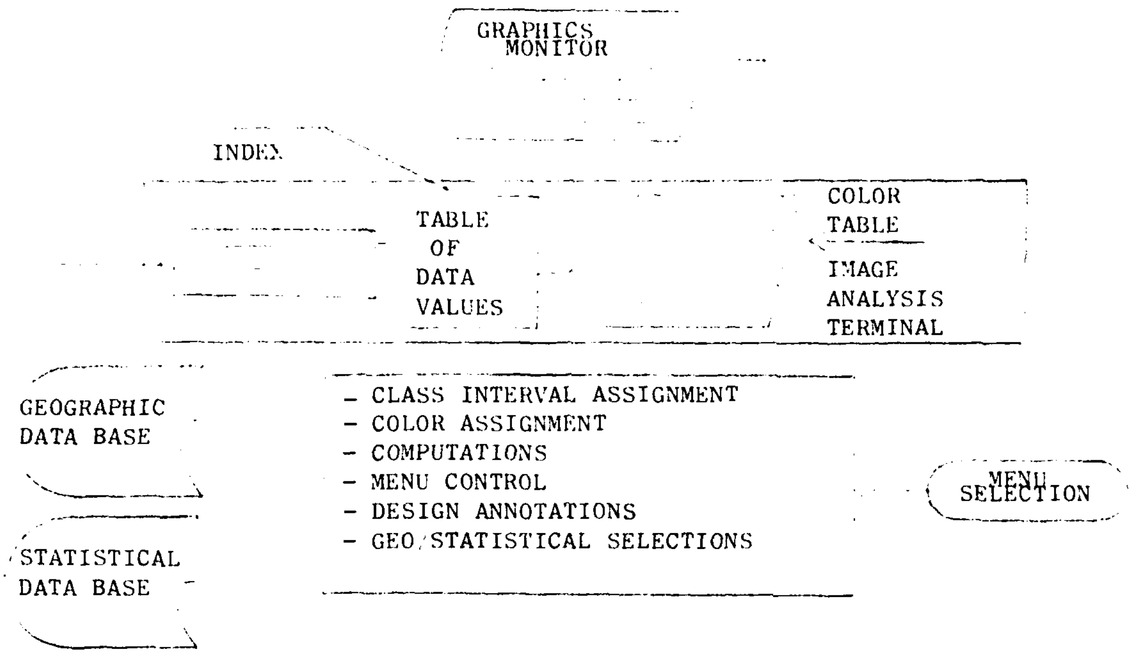
analyst wanted to see which states or which counties within the states had the highest percentage of unemployment, he would have to spend hours. With the graphics digital display system, the counties could be outlined, the percentages color coded and geographically located by a program and displayed in seconds. For example, if the analyst wanted to view unemployment by county from 1.1 to 28.1 percent, he could divide the difference by any number such as 5 to show these classes by color. Let white equal the lowest range 1.1 to 6.5 percent and let red equal the highest range. This would allow the analyst a clear view of the higher percentage counties or areas without being covered with data or lost in color. A good display is one in which the analyst can determine the facts he desires without becoming confused by statistics. The statistical information can also be displayed as a histogram with the number of counties versus the percent of unemployment values.

Other statistical items such as property tax, per capita income, education or any other information desired can be displayed on the same base map. The ranges can be as broad or as narrow as the analyst desires because of the interactive nature of the system. Class intervals can be changed by entering the desired number in the necessary algorithm. This will modify class or range assignments in the desired manner to highlight certain relationships.

This statistical system may also be used to display Standard Metropolitan Statistical Areas (SMSAs) by census tract. As more areas are required to be studied, digital information can be input as desired. As data is gathered, the interactive system requires only minutes to load with the proper information. Enlargement capabilities allow the analyst to "zoom" in on certain areas for a much more informative display. Projected growth rates, household information or declines in the birth rate may be shown in detail.

Individual states may be shown with two or more variables by increasing or changing the various color codes. This medium is extremely effective in displaying relationships between statistics. This is a primary factor in utilizing graphic image processing systems along with user interaction to determine the type of data to be investigated. The result is a system that can be used effectively by the novice as well as the experienced analyst.

The following diagram illustrates the operation of the information display system used for statistical analysis.


GRAPHICS MONITOR
INDEX
TABLE OF DATA VALUES
COLOR TABLE
IMAGE ANALYSIS TERMINAL
GEOGRAPHIC DATA BASE
STATISTICAL DATA BASE
- CLASS INTERVAL ASSIGNMENT
- COLOR ASSIGNMENT
- COMPUTATIONS
- MENU CONTROL
- DESIGN ANNOTATIONS
- GEO/STATISTICAL SELECTIONS
MENU SELECTION

GRAPHICS IMAGE HARDWARE

The graphics processing and image display system with which I am most familiar is the Image Manipulation Station. This is an interactive system used to examine digital data of various formats. The major components of the system are two graphic display monitors interfaced with a graphic processor controlled by a minicomputer. A single 800/1600 BPI 9-track tape drive is used for input and one 10-megabyte disk drive is used for storage. A control CRT console is used for terminal control, programming and menu selection.

The image display monitors are extremely flexible and perform a variety of image manipulation operations at TV-refresh rates of 1/-30th of a second. These are controlled by a graphics processor unit through which the digital matrix is mapped. The screens' refresh memory consists of 512 lines of 512 rows of 8-bit picture elements or pixels. By configuring the various matrix switches, look-up color tables and other terminal registers under computer control, the terminal can be used to perform many operations such as:

(a) False color displays

(b) Image translations - vertical and horizontal offsets (bit shifting)

(c) Image scrolling

(d) Split screen displays - rectangular subareas of different refresh memories may be composited into a single display.

(e) Interactive processing - the output of any lookup table may be re-recorded back into a refresh memory for further processing

(f) Graphic overlay of boundaries and annotation

(g) Alpha-numeric display

(h) Cursor positioning and recall of exact location parameters

The unit in control of this graphic processor is a minicomputer with 32K RAM memory. Add-on upgrade items include floating point arithmetic, disk controller, tape controller and color display interface. Added disk space for large data bases can be interfaced and fully utilized with little additional programming. The minicomputer has a real-time clock for log-on procedures and interrupt handling according to the priority of the peripheral device.

The resolution and color capabilities of the image display system are hardware limitations. Each screen has 8 planes of memory for color processing, thus allowing 16 color planes for both screens. Zoom features of 2, 4, 8 and 16 times enlargements are available. However, any zoom above 4 tends to diminish the details of the digital data.

More tape units can be added and this is now being tested for further developmental possibilities. Networking of several graphic display processors is also in the testing phase.

Several hard-copy devices are available for interfacing with the minicomputer. A printer is presently used for the output of matrix information and accounting data. Video hard copy is presently achieved by film; however, a video output hardcopy device would become an automatic peripheral unit requiring added interfacing to the display devices.

Cost and Design

Cost has a direct relationship to the degree of digital image processing desired. By decreasing the capabilities, cost can be maintained at a relatively low level. A system which can accept and generate standard video signals can directly interface to any existing piece of television equipment reducing the cost of peripheral devices for such a digital system.

The availability of microprocessors makes it easy to provide the processing capability close to the physical location where the image is to be used. These microprocessors are relatively economical and are available at various performance levels. A number of bus conventions for microcomputer connections have become popular, and a competitive market exists where many types of devices can be obtained from a wide selection of manufacturers. Peripheral devices can then be interfaced to enhance the system to the degree of utilization desired and that which can be supported with present expertise.

If current technology is exploited to full potential, three consequences can be determined:

1. Initial cost and maintenance cost of the available image input/output equipment are relatively low.

2. The system is capable of accepting and converting TV signals. If not, many manufacturers are available for digital input systems rather than video input systems.

3. The equipment is sufficiently modular to allow digital computer- controlled graphic processing equipment to be used as building blocks for a more complex system.

The station with which I am associated uses digital data gathered on three systems. The three systems are the Lineal Input System (LIS), the Advanced Graphic Digitization System (AGDS), and the Integrated Photogrammetric Instrument Network (IPIN). Not figuring the cost of this data gathering equipment, the following approximate costs can be used for the image processing system and peripherals:

1. Tape Unit 800/1600 BPI, 45 IPS with tape formatter and controller boards.

Cost $8,000.00

2. Color Display devices with processor and interface connectors. Two R-G-B monitors with interface and display memory with zoom and scroll.

Cost $25,000.00

3. Minicomputer with multiply/divide and floating point arithmetic and 32K memory.

Cost $10,000.00

4. Video CRT terminal with RS232 connectors and refresh screen with auxiliary I/O ports.

Cost $1,5000.00

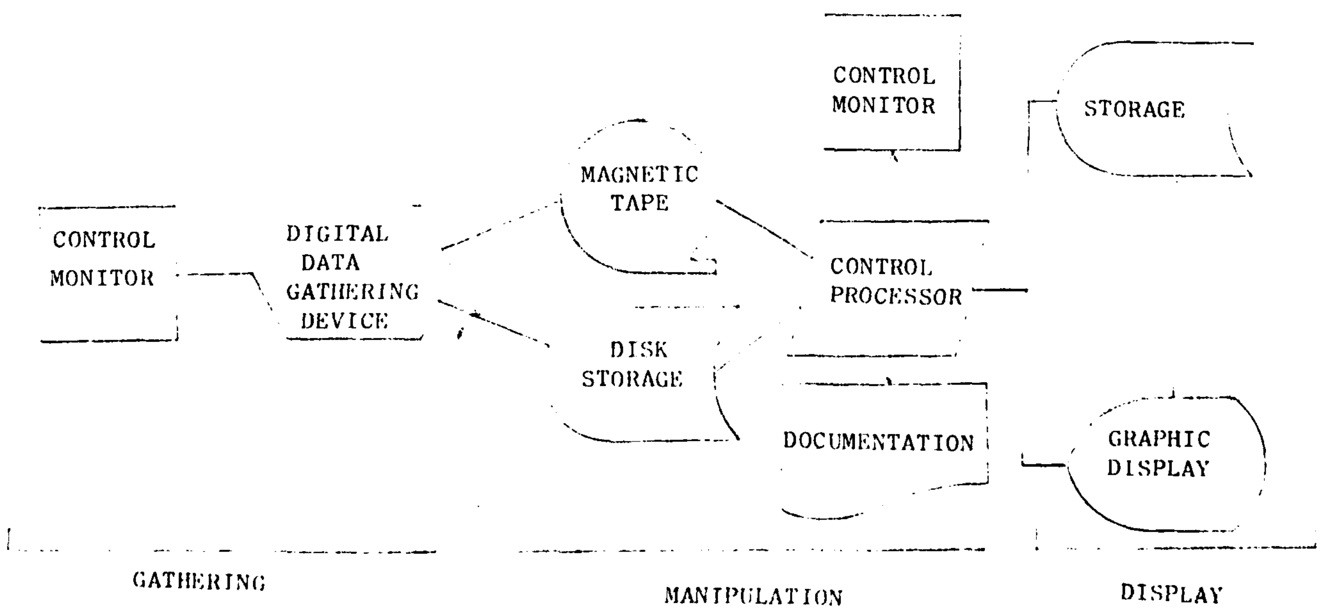
5. 10 megabyte disk drive with interface.

Cost $20,000.00

Thus the total cost of a stand-alone image processing system would be close to $75,000.00. Several other peripheral devices are available such as a video hardcopy device for $25,000.00 and line printer for $2,500.00.

The interactive digitizing system with frame buffer and digitizing table may cost about $30,000.00 with 32K of memory. Expanded memory and mass storage devices could add another $30,000.00 to provide a much more flexible system.

The following diagram is a simple design for an interactive digital image processing system.



CONCLUSION

An image processing system for the graphic display of digital cartographic, geographic, economic or spatial data is a useful tool for the scientist, educator and data analyst. All fields involved in the investigation or management of geographic/cartographic information will equally utilize the easily retrievable and identifiable image data. Plots or line drawings can be informative to the scientist but cannot be manipulated easily to enhance the utility of the information. The cartographer is constantly in search of new and useful methods of displaying portions of the earth's surface. With the advent of image processing, digital information is used to represent terrain, cultural, and economic data in a computer environment.

The field of image processing is perhaps the most important development in Computer-assisted Cartography in a decade. It has brought the science of Cartography into a new and modern era using the computer generated image as an aide to the understanding of the vast amount of information available. With a relatively small investment, the scientific and educational communities can become involved with computer graphics and image display devices.

The Defense Maping Agency, producer of large terrain and cultural digital data bases, has recognized the usefulness of an image processing system for quality control. The information and descriptions of the image system contained in this discussion were developed for the Defense Mapping Agency at the Aerospace Center. Many new algorithms and innovations are being developed at DMAAC and elsewhere for graphic display and image processing.

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Mr. Johnston received his Bachelor of Science degree in Geography in 1974 from Southern Illinois University at Edwardsville, Illinois and a Master of Science degree in Geography in 1981 from the same university. He is presently seeking a Doctors degree from Southern Illinois University at Carbondale. Mr. Johnston began his cartography career in 1975 at Surdex Corporation, Chesterfield, Missouri in photogrammetry. In 1976 he came to the Defense Mapping Agency Aerospace Center. While at DMAAC, Mr. Johnston has worked on digital data collection systems, application programming and systems programming. During this time he has been associated with the development and implementation of the Image Manipulation Station interactive graphics processing device. He is currently working in the Techniques office of the Cartographic Data Base Division, Scientific Data Department.

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